Calibration of the Isomer Shift for the 35.46 keV Mossbauer Transition of 125Te

I. 7 Calibration of the Isomer Shift for the 35.46 keV Mössbauer Transition of ^{125}Te

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The isomer shift (δ) in Mössbauer spectroscopy is expressed as a product of a nuclear quantity and an atomic one;

$$\delta = \frac{4}{5}\pi Ze^2R^2\left(\frac{\Delta R}{R}\right)\Delta|\psi(0)|^2, \qquad (1)$$

where $\Delta R/R$ is the fractional difference of the nuclear charge radius between the excited and the ground states, and $\Delta|\psi(0)|^2$ is the difference of the electron density at the nucleus for different atomic environments. In order to evaluate electron density from isomer shift data, one has to know a reliable value of $\Delta R/R$, the calibration constant of the isomer shift. To determine the value of $\Delta R/R$, it is necessary to observe both the isomer shift and $\Delta|\psi(0)|^2$ for the same sample. In this study we determined $\Delta R/R$ of the 35.46 keV M1 transition in ^{125}Te by combining the Mössbauer isomer shifts and intensities of conversion electrons of the outer-most (valence) electron shell observed in a number of metals implanted with ^{125}I.[1)]

For high resolution conversion electron measurements at energies of about 35 keV, very thin sources (less than $\sim$10 $\mu g/cm^2$) are required. In this study, the source samples were prepared by implanting radioactive ^{125}I ($T_{1/2}$=59.7 d), which decays to the Mössbauer level of ^{125}Te, into various metals (Al, Au, Cu, In, Pt, Sn, Te and Zn) by means of the EMIS (Electro-Magnetic Isotope Separator) of Tohoku University at an acceleration voltage of 20 kV at room temperature. The implantation depth was 6.4 $\mu g/cm^2$ in copper for 20 keV.[2)] The dose rate was 3×10^8 atoms/cm^2/s and the integrated dose of ^{125}I was estimated to be 3×10^{13} atoms/cm^2 ($\sim$100 μCi) from the radioactivity of the implanted sample. Thus the maximum Te concentration in samples was 0.1 atomic percent or less. In order to identify the chemical state of ^{125}Te produced within the host metal by EC-decay of ^{125}I and to determine δ, emission Mössbauer spectra were taken with a 96% eneriched $Zn^{125}Te$ absorber by keeping both the source and the absorber at liquid nitrogen temperature. Mössbauer spectra of ^{125}I implanted into Te and Au are shown in Fig. 1.

Internal conversion spectra were measured for the same samples using the high-resolution 75 cm radius iron-free $\pi\sqrt{2}$ β-ray spectrometer of INS with an instrumental momentum resolution of 5×10^{-4}. Electrons were detected in a small-volume, gas-flow proportional counter having a Mylar window of 4 μm thickness. The flow gas was isobutane at ∿100 Torr. The L, M, N and O conversion lines of the 35.46 keV transition were measured for all the samples. The N_I and O lines with the energy difference of 156 eV could be completely resolved from each other. Fig. 2 shows an example of the conversion spectrum of N and O lines measured for the Au source. The relative conversion intensity ratio α_O/α_{4s} were evaluated using the computer code ACSEMP.[3] As the contribution of O_{II} and O_{III} conversions to the observed O line is estimated to be less than 5% for the M1 transition, α_O/α_{4s} will be identified with α_{5s}/α_{4s} hereafter.

Results of the analysis of seven sources are listed in Table 1. The Mössbauer spectra of Al, Au, Cu, Pt, Sn and Zn sources could be fitted with a single Lorentzian line and that of the Te source with only one symmetric quadrupole doublet of Lorentzian lines. This fact may indicate that in those host metals Te atoms mostly occupied a unique implantation site. Since the effect of the change in 5s electron density on the inner s-electron contact densities is small, one can deduce the valence 5s electron contact density $|\psi_{5s}(0)|^2$ from the observed value of α_{5s}/α_{4s} by using the relation

$$|\psi_{5s}(0)|^2 = |\psi_{4s}(0)|^2_{theor} \times \alpha_{5s}/\alpha_{4s}, \qquad (2)$$

where $|\psi_{4s}(0)|^2_{theor}$ is a theoretical value of the contact density of 4s electrons. Using the relativistic value of Band et al.[4], $|\psi_{4s}(0)|^2 = 928$ a.u. in eq. (2), we can evaluate contact densities of 5s electrons of Te in various host materials as listed in Table 1.

The results show that the contact density of the valence 5s electrons of Te atoms in the Al metal matrix is about 20% larger than that in the Te metal matrix. Finally, in Fig. 3 the correlation of the measured isomer shifts δ and the internal conversion ratios α_{5s}/α_{4s} are shown. The fractional difference of the nuclear charge radius was derived by a least-squares fitting of eq. (1) to the data points in Fig. 3. The result is $\Delta R/R = (0.65 \pm 0.11) \times 10^{-4}$.

The measurement for the In host is still in progress.

References

1) Muramatsu H., Miura T., Nakahara H., Fujioka M., Tanaka E. and Hashizume A., Hyp. Int. 20 (1984) 305.
2) Miura T., Hatsukawa Y., Muramatsu H. and Nakahara H., to be published in Nucl. Instr. and Methods.
3) Fujioka M. and Takashima M., J. Phys. 40 (1979) C2-32.
4) Band I. M. and Fomichev V. I., Atom. Data and Nucl. Data Table 23 (1979) 295.

Talbe 1. Isomer shifts, conversion ratios and 5s electron densities[a)]

Source	Isomer Shift (mm/s)	α_{5s}/α_{4s}	$\lvert\psi_{5s}(0)\rvert^2$ (a.u.)
Sn	-0.272 ± 0.100	0.117 ± 0.004	108 ± 4
Te	-0.180 ± 0.087	0.115 ± 0.002	107 ± 2
Zn	-0.081 ± 0.039	0.119 ± 0.006	110 ± 6
Au	$+0.014\pm0.041$	0.126 ± 0.006	117 ± 6
Cu	$+0.047\pm0.024$	0.128 ± 0.004	119 ± 4
Pt	$+0.290\pm0.021$	0.135 ± 0.008	125 ± 7
Al	$+0.359\pm0.104$	0.138 ± 0.004	128 ± 4

a) $\lvert\psi_{4s}(0)\rvert^2_{theor}$ = 928.070 a.u. is used.[4)]

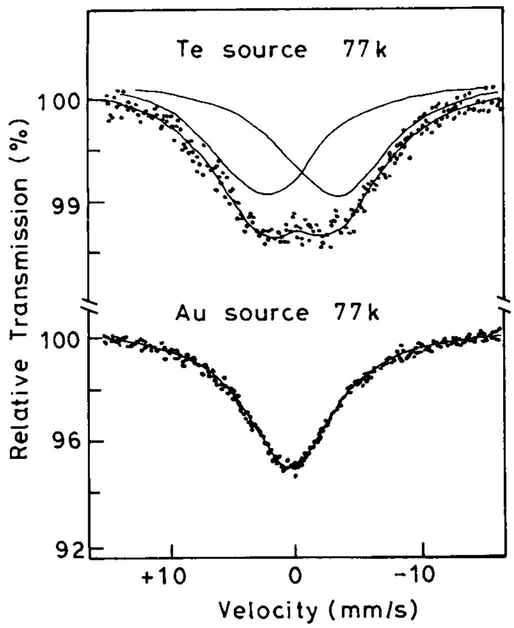

Fig. 1. Mössbauer spectra of ^{125}I implanted into Au and Te metal matrices. The spectra were measured at liquid nitrogen temperature.

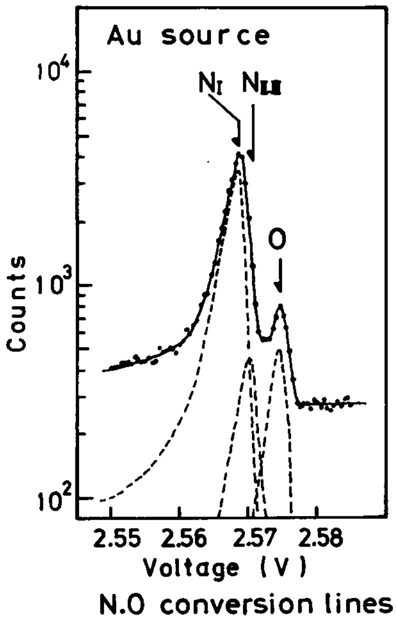

Fig. 2. The N and O conversion lines of 35.46 keV M1 transition in ^{125}Te for the Au source. The solid curve is the result of a least-squares fit, yielding the components shown by dashed lines.

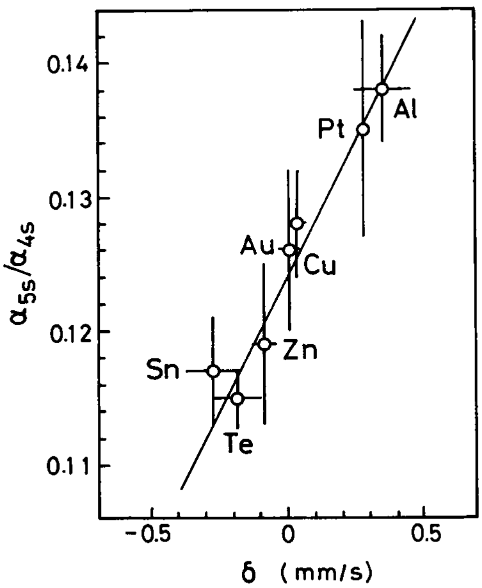

Fig. 3. The internal conversion ratio α_{5s}/α_{4s} versus the Mössbauer isomer shift as measured on ^{125}I implanted in seven different metal matrices. The solid line indicates the result of a least-squares fit.